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U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

**TRANSMITTAL LETTER TO THE UNITED STATES  
DESIGNATED/ELECTED OFFICE (DO/EO/US)  
CONCERNING A FILING UNDER 35 U.S.C. 371**

**208289US2PCT**

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

**09/831364**

INTERNATIONAL APPLICATION NO.

**PCT/FR99/02771**

INTERNATIONAL FILING DATE

**10 November 1999**

PRIORITY DATE CLAIMED

**20 November 1998**

TITLE OF INVENTION

**BIDIRECTIONAL ACTUATORS**

APPLICANT(S) FOR DO/EO/US

**Pierre GANDEL, et al.**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
  - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☒ has been transmitted by the International Bureau.
  - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
  - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☐ have been transmitted by the International Bureau.
  - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
  - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

**Items 13 to 20 below concern document(s) or information included:**

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ Certificate of Mailing by Express Mail
20. ☒ Other items or information:

**Request for Consideration of Documents Cited in International Search Report  
Notice of Priority  
PCT/IB/308**

U.S. APPLICATION NO. (IF KNOWN - SEE 37 CFR 1.53) <b>09/831364</b>	INTERNATIONAL APPLICATION NO. <b>PCT/FR99/02771</b>	ATTORNEY'S DOCKET NUM <b>208289US2PCT</b>
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21. The following fees are submitted:

**BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :**

<input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .....	<b>\$1,000.00</b>
<input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO .....	<b>\$860.00</b>
<input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO .....	<b>\$710.00</b>
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) .....	<b>\$690.00</b>
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) .....	<b>\$100.00</b>
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>	
	<b>\$860.00</b>
Surcharge of <b>\$130.00</b> for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	<b>\$130.00</b>
CLAIMS	NUMBER FILED
Total claims	- 20 = 0
Independent claims	- 3 = 0
Multiple Dependent Claims (check if applicable).	<input type="checkbox"/>
<b>TOTAL OF ABOVE CALCULATIONS =</b>	
	<b>\$990.00</b>
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (check if applicable).	<input type="checkbox"/>
<b>SUBTOTAL =</b>	
	<b>\$990.00</b>
Processing fee of <b>\$130.00</b> for furnishing the English translation later than <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).	<b>\$130.00</b>
<b>TOTAL NATIONAL FEE =</b>	
	<b>\$1,120.00</b>
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable).	<input type="checkbox"/>
<b>TOTAL FEES ENCLOSED =</b>	
	<b>\$1,120.00</b>
Amount to be: refunded \$	
charged \$	

- ☒ A check in the amount of **\$1,120.00** to cover the above fees is enclosed.
- ☐ Please charge my Deposit Account No. \_\_\_\_\_ in the amount of \_\_\_\_\_ to cover the above fees.  
A duplicate copy of this sheet is enclosed.
- ☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:



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Surinder Sachar  
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SIGNATURE

**Marvin J. Spivak**

NAME

**24,913**

REGISTRATION NUMBER

DATE

May 15 2001

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IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF: :  
PIERRE GANDEL ET AL : ATTN: APPLICATION DIVISION  
SERIAL NO: 09/831,364 :  
FILED: MAY 15, 2001 :  
FOR: BIDIRECTIONAL ACTUATORS

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS  
WASHINGTON, D.C. 20231

SIR:

Prior to a first examination on the merits, please amend the above-identified application as follows:

IN THE CLAIMS

Please cancel Claims 1-16 without prejudice.

Please add new Claims 17-32 as follows:

1. (New) A bidirectional actuator comprising at least a stator structure excited by at least one electric coil, wherein a single movable magnet is placed in a primary air gap and the stator structure comprises at least one electric coil, and is composed of a first pair of stator poles defining between them a first secondary air gap, for displacement of the single movable magnet relative to a first degree of freedom, and of a second pair of stator poles defining

between them a second secondary air gap, for displacement of the single movable magnet relative to a second degree of freedom.

18. (New) A bidirectional actuator according to claim 17, wherein the movable magnet is integral with a yoke.

19. (New) A bidirectional actuator according to claim 17, wherein the stator structure is composed of 4 poles of soft magnetic material, which define therebetween two pairs of secondary air gaps which cross at a central point and in that the primary air gap is planar.

20. (New) A bidirectional actuator according to claim 19, wherein the stator poles comprise 4 rectangular pieces, each wound by an electric coil, and defining between them two pairs of perpendicular secondary air gaps.

21. (New) A bidirectional actuator according to claim 17, wherein a ratio  $L/E$  of a thickness  $L$  of the magnet and a thickness  $E$  of the air gap ranges between 1 and 2.

22. (New) A bidirectional actuator according to claim 17, wherein dimensions of the secondary air gaps are  $C_1 + E$  and  $C_2 + E$ , where  $C_1$  and  $C_2$  denote travel ranges of the movable magnet in directions of the secondary air gaps and in that dimensions of the magnet are  $C_1 + d_1 + E$  and  $C_2 + d_2 + E$ , where  $d_1$  and  $d_2$  denote widths of the secondary air gaps.

23. (New) A bidirectional actuator according to claim 17, wherein the stator structure is composed of two stator pieces disposed one on one side and one on another side of the magnet, each stator piece having a pair of stator poles, the pair of stator poles of one of the pieces being oriented perpendicular to the pair of stator poles of the other stator piece.

24. (New) A bidirectional actuator according to claim 17, wherein the magnet has a tubular shape and is movable, in a first degree of freedom, by axial translation and, in a

second degree of freedom, by axial rotation relative to a stator structure formed from 4 stator poles in a form of cylinder portions, provided with a first secondary air gap in a longitudinal central plane, in which there is placed a first electric coil wound around at least one ferromagnetic core, and with a second secondary air gap in a transverse plane, in which there is placed a second electric coil wound around a ferromagnetic core.

25. (New) A bidirectional actuator according to claim 18, wherein the magnet has a tubular shape and is movable, in a first degree of freedom, by axial translation and, in a second degree of freedom, by axial rotation relative to an external cylindrical stator structure formed from 4 stator poles having a concave surface defining the primary air gap with the yoke placed inside the magnet, each of the four stator poles being wound by an electric coil.

26. (New) A bidirectional actuator according to claim 17, wherein the magnet has a tubular shape and is movable, in a first degree of freedom, by axial translation and, in a second degree of freedom, by axial rotation relative to a cylindrical stator structure comprising a first external stator piece for displacement in a first degree of freedom and a second internal stator piece for displacement in a second degree of freedom, each of the stator pieces having at least one electric exciting coil.

27. (New) A bidirectional actuator according to claim 17, wherein the magnet has a spherical shape and is movable in spherical rotation relative to a stator structure in a form of a spherical cup formed from 4 stator poles in a form of cup sectors provided with two coils located in peripheral grooves whose central planes are perpendicular.

28. (New) A bidirectional actuator according to claim 17, wherein the magnet has a spherical shape and is movable in spherical rotation relative to a stator structure of tubular shape formed from 4 stator poles in a form of tube quarters, wound by an electric coil.

29. (New) A bidirectional actuator according to claim 27, wherein the primary air gap has a spherical shape.

30. (New) A bidirectional actuator according to claim 17, wherein the magnet has a spherical shape and is enclosed by a spherical cup, and is movable in spherical rotation around a stator structure of spherical or hemispherical shape formed from 4 stator poles in a form of sphere quarters or eighths.

31. (New) A bidirectional actuator according to claim 17, wherein the magnet has a spherical shape and is enclosed by a cup formed from two pieces in a form of hemispheres or sphere quarters, and is movable in spherical rotation around a stator structure formed from two hemispherical stator pieces.

32. (New) A bidirectional actuator according to claim 17, wherein each of the pairs of poles defines between two adjacent poles a secondary air gap, and further comprising a sensor which is sensitive to magnetic fields and which is located in one of said secondary air gaps.

#### REMARKS

Favorable consideration of this application, as presently amended, is respectfully requested.

The present preliminary amendment is submitted to place the above-identified application in more proper format under United States practice. By the present preliminary amendment original Claims 1-16 are canceled and new Claims 17-32 are presented for examination. New Claims 17-32 are believed to be self-evident from the original disclosure, including original Claims 1-16, and thus are not deemed to raise any issues of new matter.

The present application is believed to be in condition for a full and thorough examination on the merits. An early and favorable consideration of the present application is hereby respectfully requested.

Respectfully submitted,

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<b>Marked-Up Copy</b>	
Serial No:	<u>09/831,364</u>
Amendment Filed on:	<u>08/29/07</u>

Claims 1-16 (Canceled).

Claims 17-32 (New).



BIDIRECTIONAL ACTUATORS

The present invention relates to the field of electromagnetic actuators.

Unidirectional actuators are known that use a stator structure excited by an electric coil, which produces a variable magnetic flux that ensures positioning of a movable magnet. For example, US Patent 4918987 describes such an actuator comprising a stator having two poles, each wound by a coil. The movable magnet is subjected to a linear force as a function of the flux generated by the coils.

There is also known German Patent DE 3037648, which describes a bidirectional actuator which may comprise either movable coils or movable magnets. The solution comprising movable coils is not satisfactory, because it leads to high industrialization costs. The described solution comprising movable magnets necessitates the use of 8 movable magnets. Such an architecture necessitates multiple control signals and information processing steps for fine control of the XY positioning process.

There is also known US Patent 5062055, which relates to electromagnetic actuators that produce a rotational and a translational movement simultaneously. Such a prior art actuator comprises a cylindrical magnet having magnetization fronts in the peripheral direction and in the axial direction, in which multipolar magnetization is established in the axial direction and yokes supporting coils have magnetic poles disposed facing the magnetization fronts. Such an actuator uses a magnet possessing several pairs of poles with magnetization directions that are perpendicular to one another.

The purpose of the present invention is to propose an actuator

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capable of controlling the positioning of a device in two degrees of freedom, for example in a plane defined by two perpendicular axes XY, or in one translational degree of freedom and one rotational degree of freedom, or even in spherical rotation, with simple control signals.

To this end the invention relates in its most general sense to a bidirectional actuator comprising at least a stator structure excited by an electric coil and a single movable magnet having single polarity. This magnet is placed in a primary air gap. The stator structure is composed of two stator pieces. Each of the stator pieces is provided with at least one secondary air gap and is excited by at least one electric coil. The stator structure is provided with at least one air gap for displacement of the magnet which is movable relative to a first degree of freedom, and at least one secondary air gap for displacement of the magnet that is movable relative to a second degree of freedom.

In one particular embodiment, the movable magnet is integral with the yoke.

In a first alternative, the stator structure is composed of 4 poles of soft magnetic material, which define therebetween two pairs of secondary air gaps which cross at a central point and in that the primary air gap is planar.

Advantageously, the stator poles comprise two pairs of rectangular pieces, each pair of pieces being excited by at least one electric coil and each defining a secondary air gap.

Preferably the ratio  $L/E$  of the thickness  $L$  of the magnet and the thickness  $E$  of the air gap ranges between 1 and 2.

Advantageously, the dimensions of the secondary air gaps are  $C_1 + E$  and  $C_2 + E$ , where  $C_1$  and  $C_2$  denote the travel range of the

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movable magnet in the two directions of the secondary air gaps and in that the dimensions of the magnet are  $C_1 + d_1 + E$  and  $C_2 + d_2 + E$ ,  $d_1$  and  $d_2$  denoting the width of the said secondary air gaps.

According to a particular alternative, the stator structure is composed of two stator pieces disposed one on one side and one on the other of the magnet, each stator piece having a pair of stator poles, the pair of stator poles of one of the pieces being oriented perpendicular to the pair of stator poles of the other stator piece.

According to a second alternative embodiment, the magnet has tubular shape and is movable, in a first degree of freedom, by axial translation and, in a second degree of freedom, by axial rotation relative to a stator structure formed from 4 stator poles in the form of cylindrical segments, provided with a first secondary air gap in the longitudinal central plane, in which there is placed a first electric coil, and with a second secondary air gap in the transverse plane, in which there is placed a second coil. Each of these coils is preferably wound around a ferromagnetic core.

According to an alternative, the magnet has tubular shape and is movable, in a first degree of freedom, by axial translation and, in a second degree of freedom, by axial rotation relative to an external cylindrical stator structure formed from 4 stator poles having a concave surface defining the primary air gap with the cylindrical yoke placed inside the magnet, each of the four stator poles being wound by an electric coil.

According to another alternative, the magnet has tubular shape and is movable, in a first degree of freedom, by axial translation

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and, in a second degree of freedom, by axial rotation relative to a cylindrical stator structure comprising a first external stator piece for displacement in a first degree of freedom and a second internal stator piece for displacement in a second degree of freedom, each of the stator pieces having at least one electric exciting coil.

According to a third embodiment, the magnet has spherical shape and is movable in spherical rotation relative to a stator structure in the form of a spherical cup formed from 4 stator poles in the form of cup sectors provided with two coils located in peripheral grooves whose central planes are perpendicular.

Advantageously, the magnet has spherical shape and is movable in spherical rotation relative to a stator structure of tubular shape formed from 4 stator poles in the form of tube quarters, wound by an electric coil.

According to a particular alternative of such an actuator, the primary air gap has spherical shape.

According to another particular alternative, the magnet has spherical shape and encloses a spherical cup, and is movable in spherical rotation around a stator structure of hemispherical shape formed from 4 stator poles in the form of sphere quarters.

According to a particular embodiment, the magnet has spherical shape and encloses a spherical yoke, and is movable in spherical rotation around a stator structure formed from two hemispherical stator pieces.

The invention will be better understood by reading the description hereinafter while referring to nonlimitative practical examples, illustrated by the attached drawings, wherein:

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- Figs. 1 and 2 show schematic views which are respectively in cross section and of the stator part of a first alternative in the form of an XY linear actuator;
- Figs. 3a and 3b show the functioning of the actuator;
- Figs. 4 and 5 show views of an alternative embodiment of an XY actuator;
- Figs. 6 and 7 show schematic views which are respectively in cross section and of the stator part of a first alternative embodiment in the form of an XY linear actuator;
- Figs. 8 and 9 show an alternative of an x- $\theta$  cylindrical actuator, respectively without and with the magnet;
- Figs. 10 to 12 show views in perspective, respectively without and with the magnet, and in cross section, of a linear-rotary actuator;
- Figs. 13 to 16 show views in perspective, respectively without and with the magnet, and in cross-sectional view, and in exploded view, of a second version of a linear-rotary actuator;
- Figs. 17 to 19 show views in perspective, respectively without and with the magnet, and of the stator part of a third version of a linear-rotary actuator;
- Figs. 20 and 21 show an alternative embodiment of an actuator of the "external linear and rotary" type;
- Figs. 22 and 23 show a second version of an actuator of the "external linear and rotary" type;
- Figs. 24 and 25 show a third version of an actuator of the "external linear and rotary" type;

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- Fig. 26 shows a first version of an alternative of the "Internal linear, external rotary" type;

- Figs. 27 and 27b show a modified version of an alternative of the "Internal linear, external rotary" type;

- Figs. 28 and 29 show, in three-quarters face view and in transverse view, a second version of an alternative of the "Internal linear, external rotary" type;

- Figs. 30 and 31 describe an actuator of the "external linear, internal rotary" type respectively in three-quarters face and in partial cutaway view;

- Fig. 32 shows a three-quarters face view of the stator assembly of an alternative of the "External linear, internal rotary" type;

- Figs. 33 and 34 show views of a spherical actuator and of the stator of such an actuator;

- Fig. 35 shows a view of a second version of a spherical actuator;

- Fig. 36 shows a view of a third version of a spherical actuator;

- Figs. 37 and 38 show three-quarters face and cross-sectional views of a fourth version of a spherical actuator;

- Figs. 39 and 40 show three-quarters face and cross-sectional views of a fifth version of a spherical actuator;

- Figs. 41 and 42 show three-quarters face and cross-sectional views of a sixth version of a spherical actuator;

- Figs. 43 and 44 show three-quarters face and cross-sectional

views of an actuator with position sensor.

The invention relates to a new type of actuator capable of displacing a movable part in two degrees of freedom.

The envisioned applications are:

- Information-processing applications: mouse, joystick
- Industrial applications: pick and place
- Automobile applications: gear-changing assistance.

Figs. 1 and 2 show views of a first practical example of an XY linear actuator.

The objective is to displace a movable part in a plane along 2 axes basically comprising a structure composed of a 4-pole stator, a movable magnet and a yoke that can be fixed or can move together with the magnet.

The first version presented with reference to Figs. 1 and 2 relates to a fixed-yoke actuator. In this architecture, therefore, only the magnet (14) is movable.

The actuator is then composed of the following functional parts:

- 1 flat magnet (14) composed of an isotropic or axially anisotropic magnetic alloy. In the latter case, the sense of the anisotropy must be perpendicular to the surface of the poles. It will be magnetized in this same direction.
- 1 yoke (5) of high-permeability magnetic material.
- 1 stator composed of a plane base (6) and of 4 poles (1 to 4) of rectangular cross section. It will also be made of high-permeability magnetic material.
- 4 coils (7 to 10), each wound around one of the stator poles. If necessary, a magnet support which will enclose the magnet

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to transmit the force - or the displacement - applied to an external piece.

Any shape is conceivable for this latter support.

The functioning of this actuator can be explained as follows, with reference to Figs. 3a and 3b:

If the same current  $i_1$  is passed in coils (7) and (8) and a current  $i_2$  is passed in coils (9) and (10), a potential difference is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_3$  is passed in coils (7) and (9) and a current  $i_4$  is passed in coils (8) and (10), there is created a force  $F_y$  which is proportional to the difference of magnetic potential and which is collinear with the Y axis.

This being established, it follows that, by combining the said currents, we will be able to create, by the principle of superposition, any force whose direction will lie in this plane XY.

In fact:

if, by supplying (7) and (8) by a current  $i_1$  and by supplying (9) and (10) by a current  $i_2$ , there is created a force  $F_x$

if, by supplying (7) and (9) by a current  $i_3$  and by supplying (8) and (10) by a current  $i_4$ , there is created a force  $F_y$

Then, by supplying (7) by  $i_1 + i_3$ , (8) by  $i_1 + i_4$ , (9) by  $i_2 + i_3$  and (10) by  $i_2 + i_4$ , there is created a force  $F_x + F_y$ .

This actuator therefore makes it possible to create a force whose intensity and direction can be adjusted in the plane (XY).

Let  $L$  be the thickness of the magnet,  $E$  the air gap,  $c_x$  and  $c_y$  the travel ranges of the sensor in two dimensions and  $d_x$  and  $d_y$  the pole-to-pole distances along the 2 axes.

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It will be advisable to use a ratio  $L/E$  of between 1 and 2.

If  $(c_x + E + d_x)$  and  $(c_y + E + d_y)$  are taken for dimensions of the magnet and  $(c_x + E)$  and  $(c_y + E)$  are taken for minimum dimensions of the stator poles in the measurement plane, the linearity of the force as a function of the current will be effective on both axes.

Another architecture of this actuator can be imagined according to the alternative shown in Figs. 4 and 5.

The actuator is then composed of the following functional parts:

- 1 flat magnet (14) of rectangular shape, composed of an isotropic or axially anisotropic magnetic alloy. In the latter case, the sense of the anisotropy must be perpendicular to the surface of the poles. It will be magnetized in this same direction.
- 1 X stator (20) of high-permeability magnetic material, composed of a plane base (23) and of 2 poles (21, 22) of rectangular cross section.
- 1 Y stator (28) composed of a plane base (25) and of 2 poles (26, 27) with properties analogous to those of the X stator. These two poles (26, 27) are oriented perpendicular to the poles (21, 22) of the X stator.
- 2 X coils (31, 32), each wound around one of the poles (21, 22) of the X stator.
- 2 Y coils (36, 37), each wound around one of the poles (26, 27) of the Y stator.

The coils are flat coils wound around each of the stator poles.

If necessary, a magnet support which will enclose the magnet

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to transmit the force - or the displacement - applied to an external piece.

The X stator and the Y stator are disposed one on one side and one on the other of the primary air gap in which the magnet (14) is placed. The poles (21, 22) of the X stator are oriented perpendicular to the poles (26, 27) of the Y stator, in order to urge the movable magnet in the two perpendicular directions and to ensure bidirectional displacement of the device to which it is coupled.

The functioning of this version can be explained as follows:

If a current  $i_1$  is passed in coil (31) and a current  $i_2$  is passed in coil (32), a potential difference is created along the X axis and thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_3$  is passed in coil (36) and a current  $i_4$  is passed in coil (37), there is created a force  $F_y$  which is proportional to the difference of magnetic potential and which is collinear with the Y axis.

By combining the fine control of the currents in coils (X) and in coils (Y) independently of one another, it will be possible to create a force whose amplitude and direction are adjustable in the XY plane.

Figs. 6 and 7 show schematic views which are respectively in cross section and of the stator part of a first alternative embodiment in the form of an XY linear actuator;. This alternative of the actuator has the advantage that it necessitates only a single coil per axis.

The actuator is then composed of the following functional parts:

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- 1 flat magnet (14) composed of an isotropic or axially anisotropic magnetic alloy. In the latter case, the sense of the anisotropy must be perpendicular to the surface of the poles. It will be magnetized in this same direction.
- 1 yoke (40) comprising a plate of high-permeability magnetic material.
- 1 stator (41) composed of 4 poles (42 to 45) of rectangular cross section, connected by cores around which there are wound the coils (46, 47). It will also be made of high-permeability magnetic material. In the described example, it comprises a parallelepiped block provided with perpendicular central grooves for positioning the coils and defining the stator poles (42 to 45).
- 2 crossed coils (46, 47), wound around the stator (41) in two perpendicular directions.

If necessary, a magnet support which will enclose the magnet to transmit the force or the displacement applied to an external piece.

The functioning of this version can be explained as follows:

If a current  $i_1$  is passed in coil (46), a potential difference is created along the X axis and thus a force  $F_x$  proportional to the created difference of magnetic potential and therefore to current  $i_1$  is created along the X axis.

Similarly, if a current  $i_3$  is passed in coil (47), there is created a force  $F_y$  which is proportional to the difference of magnetic potential and therefore to current  $i_2$ , and which is collinear with the Y axis.

It is then easily understood that, by combining the fine control of the currents in coils (46) and in coils (47)

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independently of one another, it will be possible to create a force whose amplitude and direction are adjustable in the XY plane.

This alternative can also be constructed in symmetric form, or in other words by replacing the yoke by an assembly of stator + coils. The amplitude of the created force will then be increased.

The stator can also be constructed in a plurality of individual parts, for example by separating the poles. There can then be obtained a version without ferromagnetic coil core or provided with independent coil cores, which would make the winding process easier.

This alternative can also be constructed as a symmetric version.

Figs. 8 and 9 show an alternative of an x- $\theta$  cylindrical actuator, respectively without and with the magnet. Several versions are conceivable. The actuator has a cylindrical structure, which therefore comprises one zone inside the magnet and one zone outside this same magnet. This structure satisfies two functions to be assured: the function of a rotary actuator and of a linear actuator. The solutions described hereinafter will be defined by the situation ("internal" or "external") of each of these functions. In general, the actuator comprises a stator structure provided with four poles (51 to 54) in the form of half cylinders and a tubular magnet (55).

The description to follow will present first of all an actuator of the "Internal linear and rotary" type.

A first solution is described in Figs. 10 to 12: it comprises using a cylindrical internal stator composed of four identical poles. Two coils are wound around each of these poles.

The actuator is then composed of the following functional

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parts:

- 1 annular half magnet (60) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This can be independent or adhesively bonded to the yoke (61).
- 1 annular yoke (61) of high-permeability magnetic material.
- 1 stator composed of 4 poles (62 to 65) of cylindrical external shape, connected by cores (70, 71) around which there are wound the coils (66 to 69). It will also be made of high-permeability magnetic material. Depending on manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces.
- 4 coils (66 to 69), wound around the stator.

The functioning of this actuator can be explained as follows:

If the same current  $i_1$  is passed in coils (66) and (67) and a current  $i_2$  is passed in coils (68) and (69), a potential difference is created along the X axis and thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_3$  is passed in coils (66) and (68) and a current  $i_4$  is passed in coils (67) and (69), there is created in this case, on the magnet, a torque  $M_x$  which is collinear with the X axis and is proportional to the created difference of magnetic potential.

This being established, it follows that, by combining the said currents, we will be able to create, by the principle of superposition, any "force-torque" combination whose direction is collinear with the X axis.

In fact:

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if, by supplying (66) and (67) by a current  $i_1$  and by supplying (68) and (69) by a current  $i_2$ , there is created a force  $F_x$

if, by supplying (66) and (68) by a current  $i_3$  and by supplying (67) and (69) by a current  $i_4$ , there is created a torque  $M_x$

Then, by supplying (66) by  $i_1 + i_3$ , (67) by  $i_1 + i_4$ , (68) by  $i_2 + i_3$  and (69) by  $i_2 + i_4$ , there is created a force  $F_x$  and a torque  $M_x$ .

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

Figs. 13 to 16 show a second solution of a linear-rotary actuator.

This second solution comprises replacing 2 of the 4 coils of the preceding solution by one coil mounted on the primary axis of the mechanism. This, denoted (4L), will assure the "axial force" part and the 2 others will create the torque.

The actuator is then composed of the following functional parts:

- 1 annular half magnet (60) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This can be independent or adhesively bonded to the yoke.
- 1 annular yoke (61) of high-permeability magnetic material.
- 1 stator composed of 4 poles (62 to 65) of cylindrical external shape. The half moons facing one another radially are connected 2 by 2 by cores (70, 71) around which there are wound the coils (4R). The assemblies formed in this way will

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be connected by an axial core (72), around which there will be wound the coil (4L). All these poles will also be made of high-permeability magnetic material. Depending on manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces (see Fig. 16).

- 2 longitudinal coils (4R).
- 1 transverse coil (4L).

If necessary, a magnet support which will enclose the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If the current  $i_1$  is passed in the coil (4L), a difference in magnetic potential is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in coils (4R), there is created in this case, on the magnet, a torque  $M_x$  which is collinear with the X axis and is proportional to the created difference of magnetic potential.

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

Figs. 17 to 19 show a third version of a linear-rotary actuator. The stator is formed by one cylindrical piece having 4 poles (62 to 65) in the form of half-cylinders. In this solution, the 2 coils noted in the foregoing (4R) are replaced by a single coil. Thus there are ultimately obtained 2 crossed coils, as illustrated in Figs. 17 to 19.

The functioning of this actuator can be explained as follows:

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If a current  $i_1$  is passed in the coil (4L), a difference in magnetic potential is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in the coil (4R), there is created in this case, on the magnet, a torque  $M_x$  which is collinear with the X axis and is proportional to the created difference of magnetic potential.

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

Another structure could also be obtained by dividing the coil (4L) into 3 or four coils mounted one on each side of the axial poles.

Figs. 20 and 21 show an alternative embodiment of an actuator of the "external linear and rotary" type.

All the versions described in this part are actually homologous versions of the versions described in the preceding part: the only difference is that the internal and external parts are interchanged. They will nevertheless be described for the sake of clarity.

In the version shown in Figs. 20 and 21 there are disposed four external coils, each wound around one pole.

The actuator is then composed of the following functional parts:

- 1 annular half magnet (80) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This can be independent or adhesively bonded to the yoke.

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- 1 cylindrical yoke (81) of high-permeability magnetic material.
- 1 stator composed of 4 poles (82 to 85) of cylindrical internal shape, connected by a common base. It will also be made of high-permeability magnetic material. Depending on manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces.
- 4 coils (86 to 89), wound around the stator poles respectively (82 to 85).

If necessary, a magnet support which will enclose the magnet to transmit the force - or the displacement - applied to an external piece.

This version functions in a manner similar to the version shown by referring to Figs. 10 to 12:

In fact, by supplying (86) by  $i_1 + i_3$ , (87) by  $i_1 + i_4$ , (88) by  $i_2 + i_3$  and (89) by  $i_2 + i_4$ , there is created a force  $F_x$  and a torque  $M_x$ .

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

Figs. 22 and 23 show a second version of an actuator of the "linear-rotary" type.

The actuator is then composed of the following functional parts:

- 1 annular half magnet (90) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This can be independent or adhesively bonded to the yoke.
- 1 cylindrical yoke (95) of high-permeability magnetic

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material.

- 1 stator composed of 4 poles (91 to 94) and of a common structure (96). Around poles (91, 92) there are wound coils (4R) (97, 98). Coil (4L) will be situated between the poles as shown in Fig. 22. All these poles (91 to 94) will also be made of high-permeability magnetic material. Depending on manufacturing preferences, the whole may be made of a single piece or of an assembly of ferromagnetic pieces.
- 2 coils (4R).
- 1 coil (4L).

The functioning of this actuator can be explained as follows:

If the current  $i_1$  is passed in the coil (4L), a difference in magnetic potential is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in coils (4R), there is created in this case, on the magnet, a torque  $M_x$  which is collinear with the X axis and is proportional to the created difference of magnetic potential.

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

The coils (4L) and (4R) are shown here with rectangular shape to make it easy to read the drawing, but it is self-evident that they could also have, for example, cylindrical shape.

With a view to increasing the torque, it is also possible to dispose 4 coils (4R) in such a way that 2 are disposed on the 2 unused stator poles.

Figs. 24 and 25 show a third version of an actuator of the

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"linear-rotary" type, with 2 crossed coils. The actuator according to this third version is composed of the following functional parts:

- 1 annular half magnet (90) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This can be independent or adhesively bonded to the yoke.
- 1 cylindrical yoke (95) of high-permeability magnetic material.
- 1 stator composed of 4 poles (91 to 94) and of a common structure (96). Around 2 of those poles there will be wound coil (4R). Coil (4L) will be situated between the poles (91 to 94). All these poles will also be made of high-permeability magnetic material. Depending on manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces.
- 1 coil (4R).
- 1 coil (4L).

If necessary, a magnet support which will enclose the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If the current  $i_1$  is passed in the coil (4L), a difference in magnetic potential is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in the coil (4R), there is created in this case, on the magnet, a torque  $M_x$  which is collinear with the X axis and is proportional to the created

difference of magnetic potential.

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

Another structure could also be obtained by dividing the coil (4L) into 3 or four coils mounted one on each side of the axial poles, or by adding a second coil (4R), which is axially symmetric relative to the first.

Finally, for each of these versions, another structure could also be obtained by multiplying the stator structure by using a plurality of stators. In this way there is obtained a structure with more external poles, with a plurality of magnets, which offers a smaller angular travel range but a larger torque. In this way it is possible to imagine any structure of  $(2N)$  radial poles separated by angles of  $(360^\circ/2N)$ , with N magnets.

Fig. 26 shows a first version of an alternative of the "Internal linear, external rotary" type. The actuator is then composed of the following functional parts:

- 1 annular half magnet (100) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This must be independent of the two stators.
- 1 cylindrical stator of high-permeability magnetic material, composed of two poles (101, 102) of the same diameter. Coil (103) will be situated between these two poles, around a ferromagnetic core.
- 1 stator composed of 2 poles (104, 105) and of a common structure (108). Around them there will be wound coils (106, 107). These poles (104, 105) will also be made of high-permeability magnetic material. Depending on manufacturing

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preferences, this stator may be made of a single piece or of an assembly of ferromagnetic pieces.

- 1 coil (106).
- 1 coil (107).

If necessary, a magnet support which will enclose the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If a current  $i_1$  is passed in the coil (103), a difference in magnetic potential is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in coils (106, 107), there is created in this case, on the magnet, a torque  $M_x$  which is collinear with the X axis and is proportional to the created difference of magnetic potential.

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

Another structure could also be obtained by multiplying the external stator structure according to Fig. 27. In this way there is obtained a structure with more external poles (110, 111, 112, 113), with a plurality of magnets (115, 116), which offers a smaller angular travel range but a larger torque. In this way it is possible to imagine any structure of  $(2N)$  radial poles. This multiplication principle can also be applied to each cylindrical structure described in this text.

Another structure could also be obtained by using only a single coil for creation of a torque. Figs. 28 and 29 show three-

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quarters face and cross-sectional views of such a version. This comprises a novel arrangement of the external part of the actuator such that only 2 coils are needed. The actuator is then composed of the following functional parts:

- 1 annular half magnet (120) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This must be independent of the two stators.
- 1 cylindrical stator of high-permeability magnetic material, composed of two poles (121, 122) of the same diameter. Coil (125) will be situated around this stator, between the 2 poles (121, 122).
- 1 stator composed of 2 poles (123, 124) and of a common structure. Coil (126) is wound around this stator, between the 2 poles (123, 124). These poles will also be made of high-permeability magnetic material. Depending on manufacturing preferences, this stator may be made of a single piece or of an assembly of ferromagnetic pieces.
- 1 coil (125).
- 1 coil (126).

If necessary, a magnet support which will enclose the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If a current  $i_1$  is passed in the coil (125), a difference in magnetic potential is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in the coil (126), there is created in this case, on the magnet, a torque  $M_x$  which is

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collinear with the X axis and is proportional to the created difference of magnetic potential.

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

Figs. 30 and 31 describe an actuator of the "External linear, internal rotary" type.

The actuator is composed of the following functional parts:

- 1 annular half magnet (140) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This must be independent of the two stators.
- 1 cylindrical stator of high-permeability magnetic material, composed of two poles (141, 142) of the same diameter. Coil (143) will be situated between the 2 poles.
- 1 stator (2R) composed of 2 poles (144, 145) and of a common core. Coil (146) will be situated such that it is wound around this core, between the 2 poles (144, 145). These poles will also be made of high-permeability magnetic material.
- 1 coil (143).
- 1 coil (146).

If necessary, a magnet support which will enclose the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If a current  $i_1$  is passed in the coil (143), a difference in magnetic potential is created along the X axis: thus a force  $F_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in the coil (146), there

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is created in this case, on the magnet, a torque  $M_x$  which is collinear with the X axis and is proportional to the created difference of magnetic potential.

This actuator therefore makes it possible to create simultaneously a force and a torque whose intensities are adjustable, both collinear with the X axis.

It is to be noted that, by constructing the stator in the form of four quarter cylinders (150 to 153), around which there are wound 2 coils (154, 155) (see Fig. 32), there is obtained a version with 4 poles in rotational direction, having a reduced travel range of less than  $90^\circ$  but furnishing a larger torque. There will then be used 2 magnets with angular width of  $90^\circ$ .

Figs. 33 and 34 show views of an  $\alpha$ - $\beta$  spherical actuator and of its stator.

Several versions are conceivable. The solutions described hereinafter will be defined by the ("internal" or "external") situation of the two functions (rotation around 2 axes) assured by the actuator.

The actuator is composed of the following functional parts:

- 1 spherical half magnet (200) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This can be independent or adhesively bonded to the yoke, as shown in the figure (33).
- 1 hollow spherical yoke (201) of high-permeability magnetic material.
- 1 stator composed of 4 poles (202 to 205) of spherical external shape, connected by cores around which there will be wound the four coils (206 to 209). It will also be made of high-permeability magnetic material. Depending on

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manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces.

- 4 coils (206 to 209), wound around the stator.

If necessary, a magnet support which will be fixed to the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If the same current  $i_1$  is passed in the coils (206) and (208), a difference in potential with respect to rotation around the X axis is created and thus a torque  $M_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in the coils (207) and (209), there is created in this case, on the magnet, a torque  $M_y$  which is collinear with the Y axis and is proportional to the created difference of magnetic potential.

By combining the said currents, we will be able to create, by the principle of superposition, any torque whose axis will lie in this plane XY.

In fact:

By supplying (206) and (208) by a current  $i_1$ , there is created a torque  $M_x$

By supplying (207) and (209) by a current  $i_2$ , there is created a torque  $M_y$

Then, by supplying (206) and (208) by  $i_1$ , (207) and (209) by  $i_2$ , there are created a torque  $M_x$  and a torque  $M_y$ .

This actuator therefore makes it possible to create independent torques along two orthogonal axes.

Fig. 35 shows a second version of a spherical actuator. The actuator is composed of the following functional parts:

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- 1 spherical half magnet (210) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This can be independent or adhesively bonded to the yoke, as shown in the figure (35).
- 1 hollow spherical yoke (211) of high-permeability magnetic material.
- 1 stator composed of 4 poles (212 to 215) of spherical external shape, connected by cores around which there will be wound the coils (216, 217). It will also be made of high-permeability magnetic material. Depending on manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces.
- 2 crossed coils (216) and (217), wound around the stator.

If necessary, a magnet support which will be fixed to the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If a current  $i_1$  is passed in the coil (216), a difference in potential with respect to rotation around the X axis is created and thus a torque  $M_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in the coil (217), there is created in this case, on the magnet, a torque  $M_y$  which is collinear with the Y axis and is proportional to the created difference of magnetic potential.

By combining the said currents, we will be able to create, by the principle of superposition, any torque whose axis will lie in this plane XY.

Fig. 36 corresponds to another arrangement of this same

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system, which can be more easily constructed industrially but which has a shorter travel range.

The stator parts are constructed in the form of spherical sector quarters (220 to 223). They are wound by two coils (224, 225).

Figs. 37 and 38 show views of a spherical actuator of the "All external" type.

The principle of this solution comprises interchanging the architecture of the preceding actuator, by placing the yoke and magnet inside and the stator poles outside.

The first version of this actuator is composed of the following functional parts:

- 1 magnet in the form of a spherical cup (230) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized.
- 1 spherical yoke (231) of high-permeability magnetic material.
- 1 stator composed of 4 poles (232 to 235) having external shape in the form of cylinder quarters and spherical internal shape, connected by cores around which there will be wound the coils (236 to 239). It will also be made of high-permeability magnetic material. Depending on manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces.
- 4 coils (236 to 239), wound around the stator, 2 per axis of rotation.

If necessary, a magnet support which will be fixed to the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator is in every respect the same

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as that of the first spherical actuator described in this text.

Figs. 39 and 40 show a second version of a spherical actuator of the "all external" type.

The actuator is composed of the following functional parts:

- 1 magnet in the form of a spherical cup (250) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized.
- 1 spherical yoke (251) of high-permeability magnetic material.
- 1 stator composed of 4 poles (252 to 255) of spherical internal shape, connected by cores around which there will be wound the coils (256, 257). It will also be made of high-permeability magnetic material. Depending on manufacturing preferences, it may be made of a single piece or of an assembly of ferromagnetic pieces.
- 2 coils (256, 257), wound around the stator, 1 per axis of rotation.

The functioning of this actuator is in every respect the same as that of the spherical actuator illustrated in Figs. 35 and 36.

Figs. 41 and 42 show three-quarters face and partial cutaway views of a hybrid actuator (internal and external).

The actuator is composed of the following functional parts:

- 1 magnet in the form of a spherical cup (260) composed of an isotropic or radially anisotropic magnetic alloy, which is radially magnetized. This must be independent of the two stators.
- 1 internal stator, of spherical external shapes, of high-permeability magnetic material. It has 2 poles (261, 262) connected by a core, around which there is wound the coil (265).
- 1 external stator composed of 2 poles (263, 264) of spherical internal shape, connected by a core around which there will be wound the coil (266). It will also be made of high-permeability magnetic material.
- 1 coil (266), wound around the external stator.
- 1 coil (265), wound around the internal stator.

If necessary, a magnet support which will be fixed to the magnet to transmit the force - or the displacement - applied to an external piece.

The functioning of this actuator can be explained as follows:

If a current  $i_1$  is passed in the coil (266), a difference in potential with respect to rotation around the X axis is created and thus a torque  $M_x$  proportional to the created difference of magnetic potential is created along the X axis.

Similarly, if a current  $i_2$  is passed in the coil (265), there is created in this case, on the magnet, a torque  $M_y$  which is collinear with the Y axis and is proportional to the created difference of magnetic potential.

By combining the said currents, we will be able to create, by the principle of superposition, any torque whose axis will lie in

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this plane XY.

Each of the foregoing electromagnetic systems can be coupled with contactless dimensional position sensors.

There will then be obtained a "sensor-actuator" assembly capable of assuring two functions in the same volume and thus of working in closed-loop manner.

For this purpose the iron parts between the stator poles (in other words, those around which the coils will be wound, generally referred to as "core" throughout this patent) must be separated by means of a slot.

An element that is sensitive to magnetic fields (such as a Hall-effect sensor) will then be positioned in the said slot.

Figs. 43 and 44 illustrate the application of this principle to a plane XY actuator.

The position sensor makes it possible to measure the flux variations created by a magnet that is movable in an air gap.

The stator comprises four rectangular parts (300 to 303) wound by four coils (310 to 313). A thin transversely magnetized magnet (305) is placed in the primary air gap (307) formed between the stator and the yoke (306). Four Hall sensors (320 to 323) are placed in the secondary air gaps between the stator parts (300 to 303).

In the described architecture, the sensors will measure a flux variation due to the displacement of the magnet and to the current circulating in the coils. We must therefore "separate" this flux due to the current. This can be accomplished in two ways:

By measuring the current in the coils and calculating the flux induced by the current, to subtract it from the measured value. In fact, the total flux is the sum of the flux due to the current and

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of the flux due to the magnet ( $\Phi_t = \Phi_{ni} + \Phi_a = A.ni + \Phi_a$ ). Knowing the impedance  $A$  of the magnetic circuit and the current in the coils, it is easily possible to calculate  $\Phi_a$ . The intensity can be measured by any conceivable means (for example, by recording the voltage drop at the leads of a sampling resistor through which the said current is passing).

By alternating the "sensor" and "actuator" functions. During a given time interval, the coils will be supplied in order to produce the desired force (or torque) and, during the following interval, the supply of the coils will be suspended in order that only the flux due to the magnet is now being measured. Thus there will be obtained an intermittent force that can be used for functions of the joystick type.

**CLAIMS**

1 - A bidirectional actuator comprising at least a stator structure excited by at least one electric coil, characterized in that it comprises a single movable magnet placed in a primary air gap and in that the stator structure comprises at least one electric coil, and is composed of a first pair of stator poles (1, 2) defining between them a first secondary air gap, for displacement of the single movable magnet (14) relative to a first degree of freedom, and of a second pair of stator poles (3, 4) defining between them a second secondary air gap, for displacement of the single movable magnet (14) relative to a second degree of freedom.

2 - A bidirectional actuator according to claim 1, characterized in that the movable magnet is integral with a yoke (25).

3 - A bidirectional actuator according to claim 1 or 2, characterized in that the stator structure is composed of 4 poles of soft magnetic material, which define therebetween two pairs of secondary air gaps which cross at a central point and in that the primary air gap (10) is planar.

4 - A bidirectional actuator according to claim 3, characterized in that the stator poles comprise 4 rectangular pieces, each wound by an electric coil, and defining between them two pairs of perpendicular secondary air gaps.

5 - A bidirectional actuator according to at least one of the preceding claims, characterized in that the ratio  $L/E$  of the thickness  $L$  of the magnet and the thickness  $E$  of the air gap ranges between 1 and 2.

6 - A bidirectional actuator according to at least one of the

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preceding claims, characterized in that the dimensions of the secondary air gaps are  $C_1 + E$  and  $C_2 + E$ , where  $C_1$  and  $C_2$  denote the travel range of the movable magnet in the two directions of the secondary air gaps and in that the dimensions of the magnet are  $C_1 + d_1 + E$  and  $C_2 + d_2 + E$ , where  $d_1$  and  $d_2$  denote the widths of the secondary air gaps.

7 - A bidirectional actuator according to claim 1 or 2, characterized in that the stator structure is composed of two stator pieces disposed one on one side and one on the other of the magnet, each stator piece having a pair of stator poles, the pair of stator poles of one of the pieces being oriented perpendicular to the pair of stator poles of the other stator piece.

8 - A bidirectional actuator according to claim 1 or 2, characterized in that the magnet has tubular shape and is movable, in a first degree of freedom, by axial translation and, in a second degree of freedom, by axial rotation relative to a stator structure formed from 4 stator poles in the form of cylinder portions, provided with a first secondary air gap in the longitudinal central plane, in which there is placed a first electric coil wound around at least one ferromagnetic core, and with a second secondary air gap in the transverse plane, in which there is placed a second electric coil wound around a ferromagnetic core.

9 - A bidirectional actuator according to claim 1 or 2, characterized in that the magnet has tubular shape and is movable, in a first degree of freedom, by axial translation and, in a second degree of freedom, by axial rotation relative to an external cylindrical stator structure formed from 4 stator poles having a concave surface defining the primary air gap with the cylindrical yoke placed inside the magnet, each of the four stator poles being

wound by an electric coil.

10 - A bidirectional actuator according to claim 1 or 2, characterized in that the magnet has tubular shape and is movable, in a first degree of freedom, by axial translation and, in a second degree of freedom, by axial rotation relative to a cylindrical stator structure comprising a first external stator piece for displacement in a first degree of freedom and a second internal stator piece for displacement in a second degree of freedom, each of the stator pieces having at least one electric exciting coil.

11 - A bidirectional actuator according to claim 1 or 2, characterized in that the magnet has spherical shape and is movable in spherical rotation relative to a stator structure in the form of a spherical cup formed from 4 stator poles in the form of cup sectors provided with two coils located in peripheral grooves whose central planes are perpendicular.

12 - A bidirectional actuator according to claim 1 or 2, characterized in that the magnet has spherical shape and is movable in spherical rotation relative to a stator structure of tubular shape formed from 4 stator poles in the form of tube quarters, wound by an electric coil.

13 - A bidirectional actuator according to claim 11, characterized in that the primary air gap has spherical shape.

14 - A bidirectional actuator according to claim 1 or 2, characterized in that the magnet has spherical shape and is enclosed by a spherical cup, and is movable in spherical rotation around a stator structure of spherical or hemispherical shape formed from 4 stator poles in the form of sphere quarters or eighths.

15 - A bidirectional actuator according to claim 1 or 2, characterized in that the magnet has spherical shape and is enclosed by a cup formed from two pieces in the form of hemispheres or sphere quarters, and is movable in spherical rotation around a stator structure formed from two hemispherical stator pieces.

16 - A bidirectional actuator according to at least one of the preceding claims, characterized in that each of the pairs of poles (1, 2), (3, 4) defines between two adjacent poles a secondary air gap, and in that it contains a sensor which is sensitive to magnetic fields and which is located in the said secondary air gap.

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Fig.1

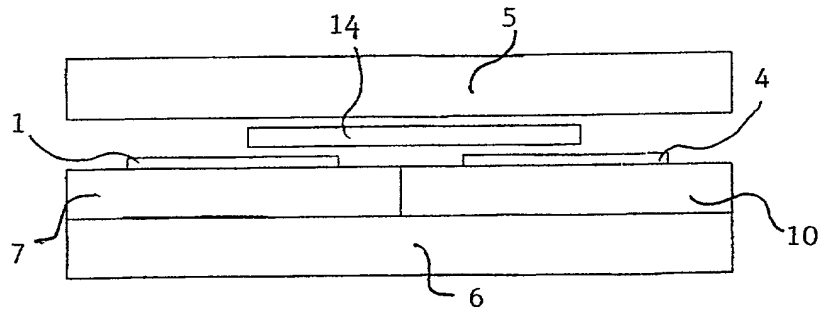
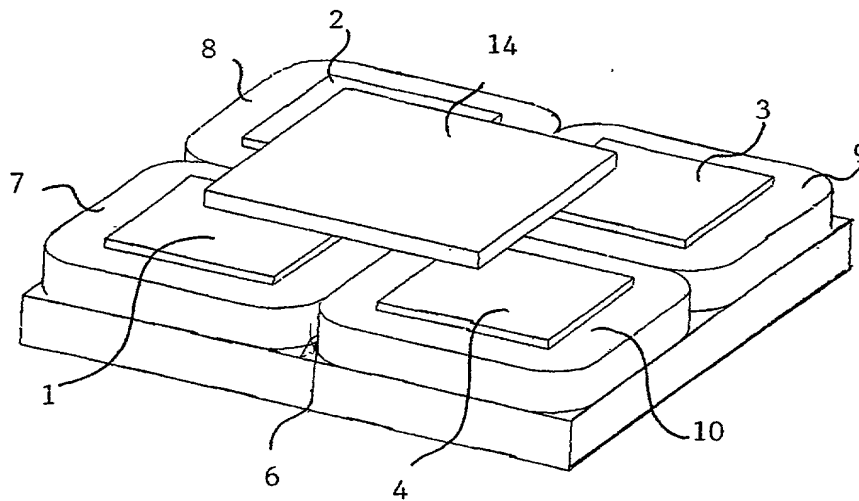


Fig.2



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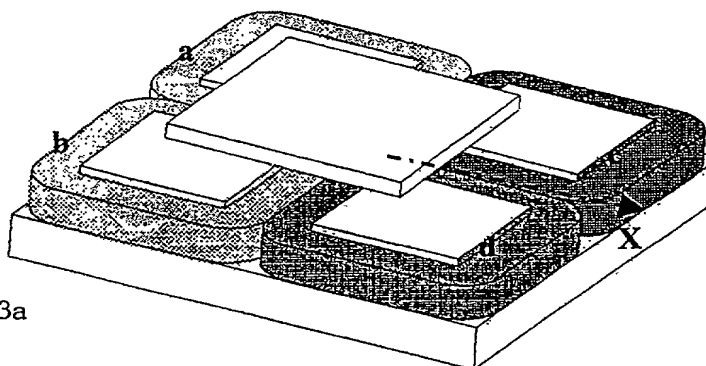


Fig. 3a

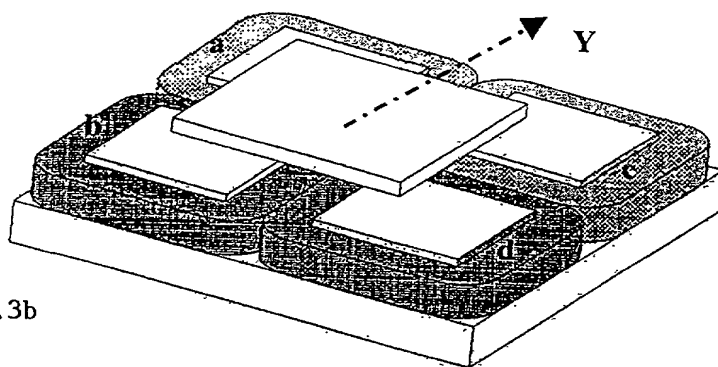


Fig. 3b

Fig. 4

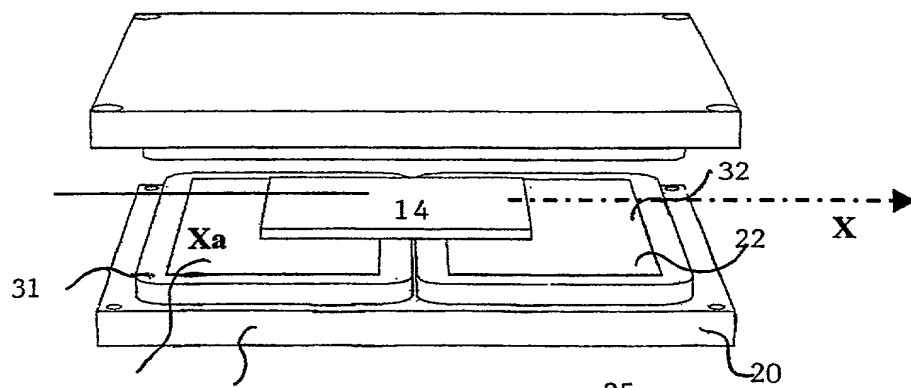
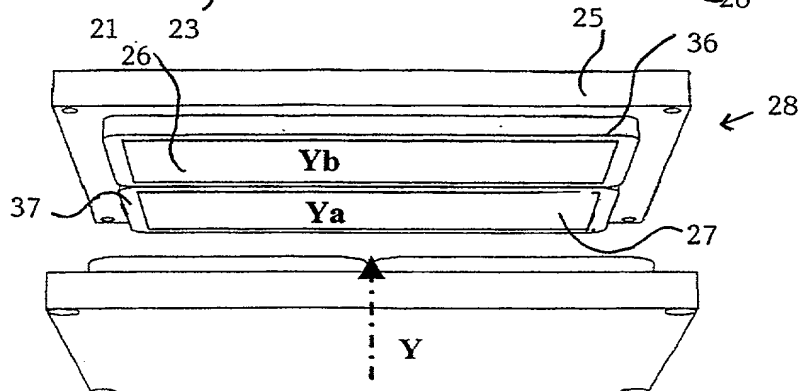


Fig. 5



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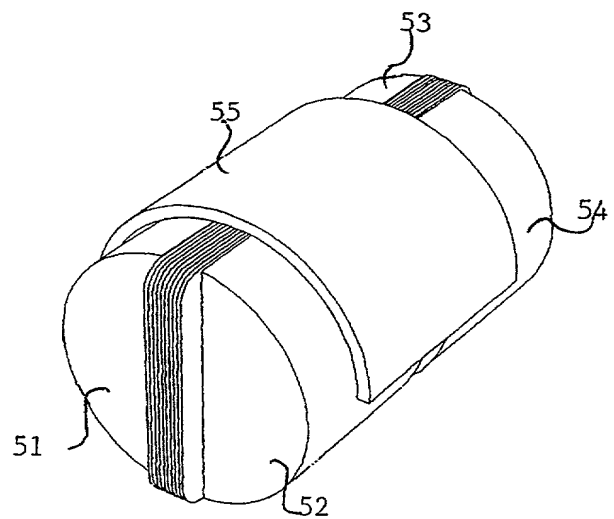
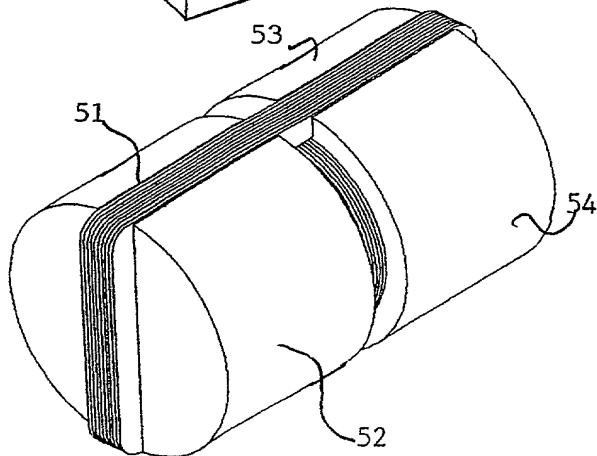
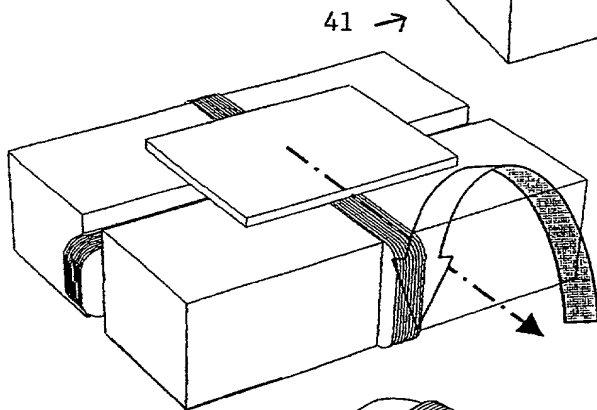
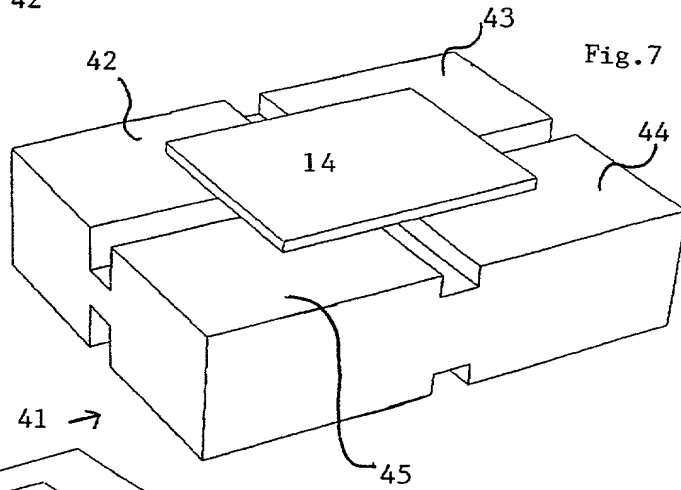
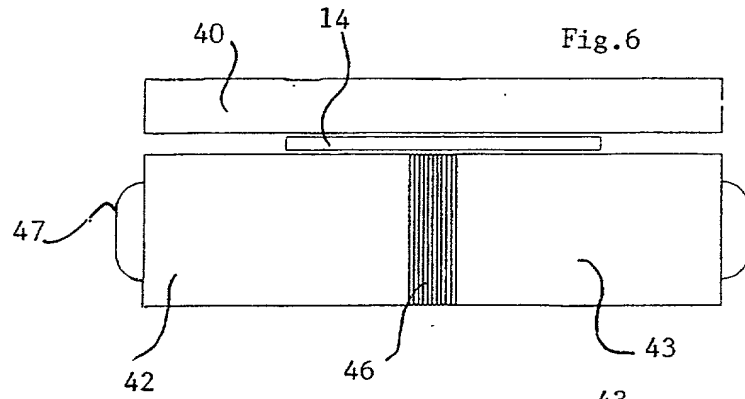


Fig. 9

Fig.10

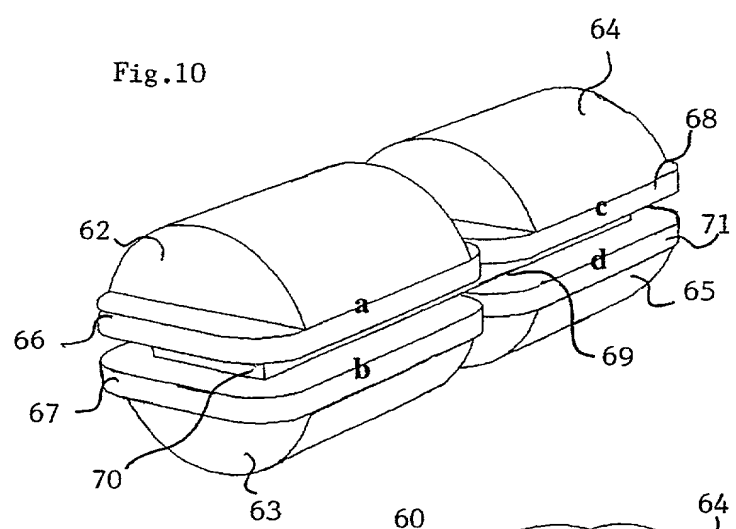


Fig.11

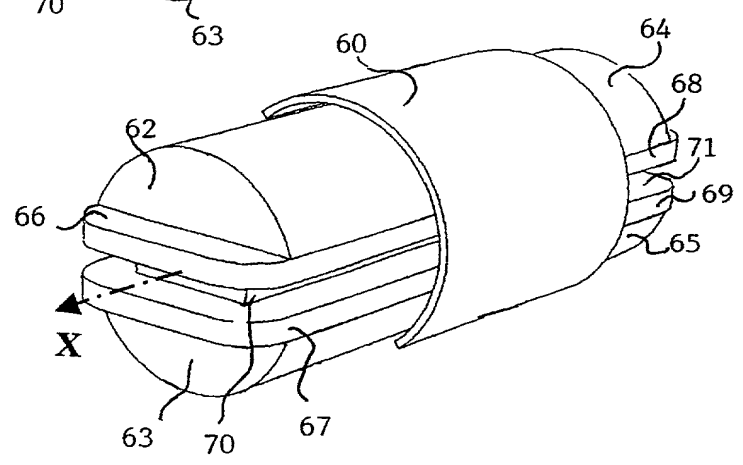
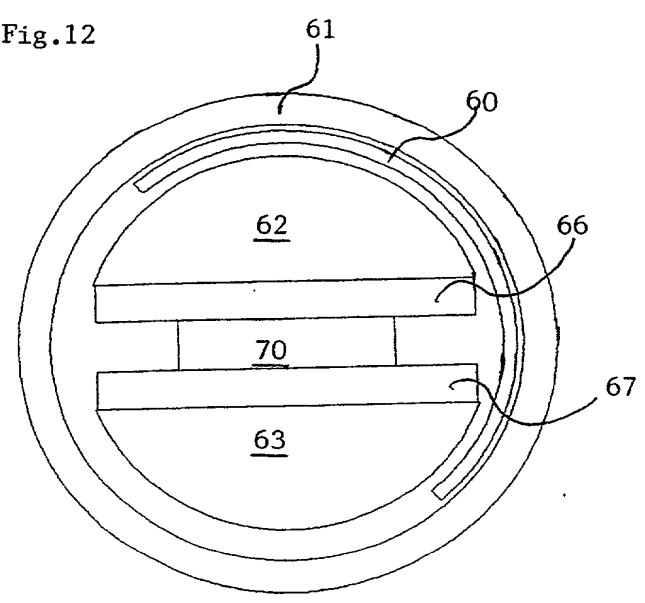


Fig.12



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Fig.13

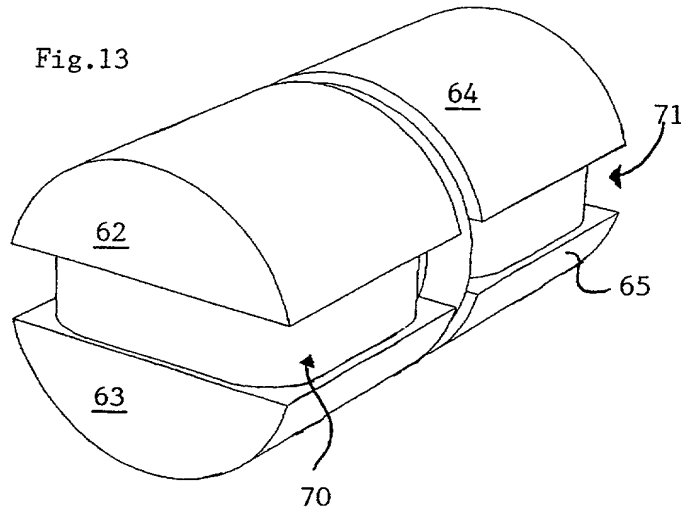


Fig.14

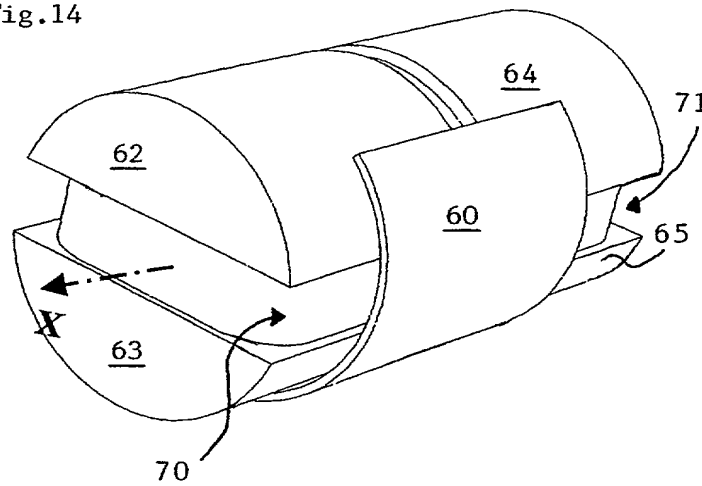
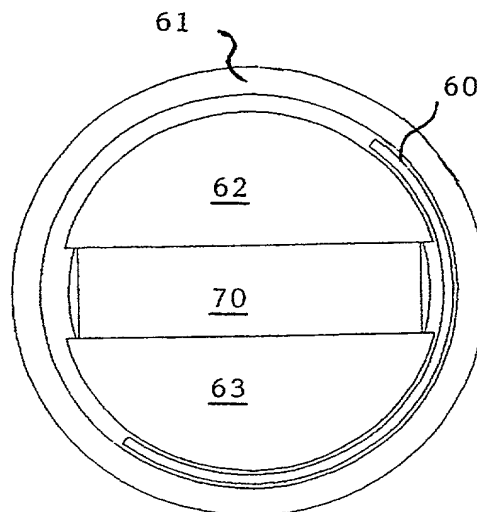


Fig.15



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Fig.16

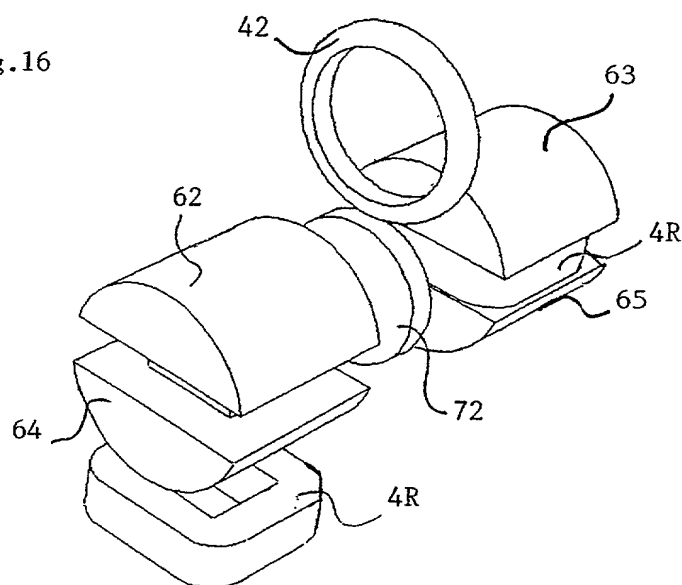


Fig.17

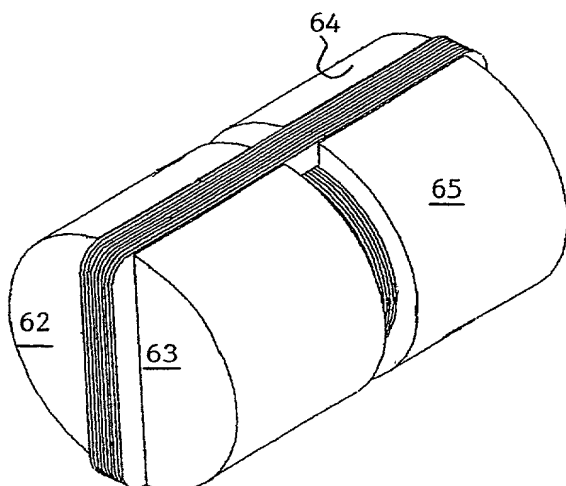


Fig.18

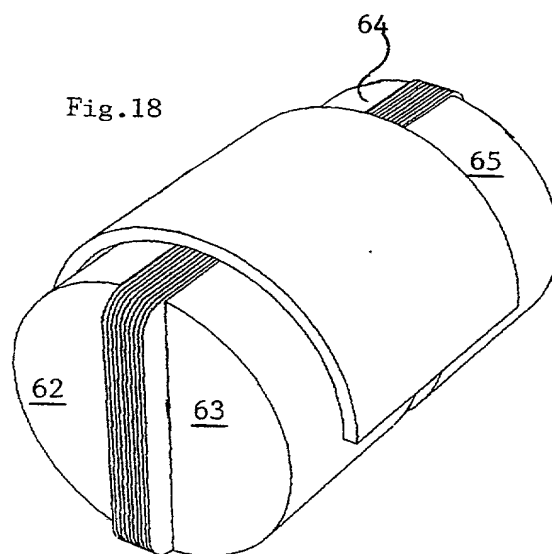
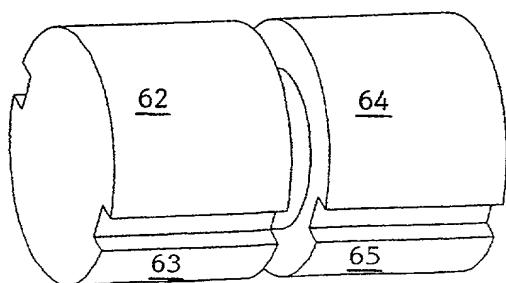


Fig.19



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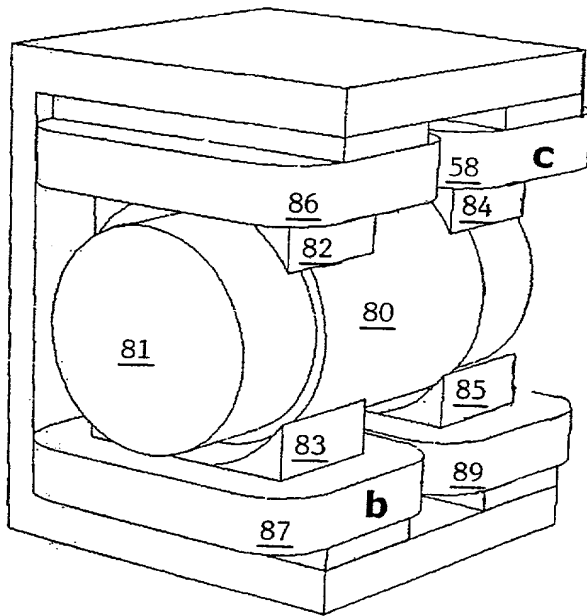


Fig. 20

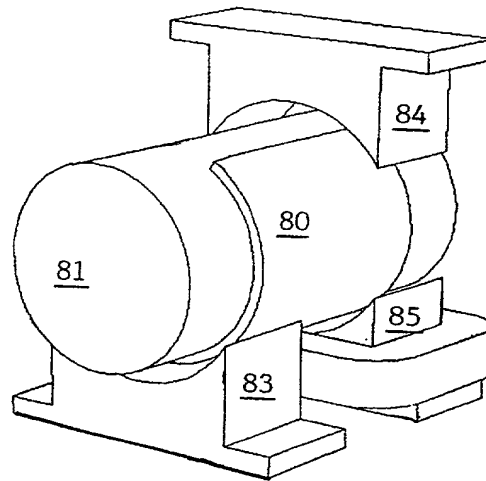


Fig. 21

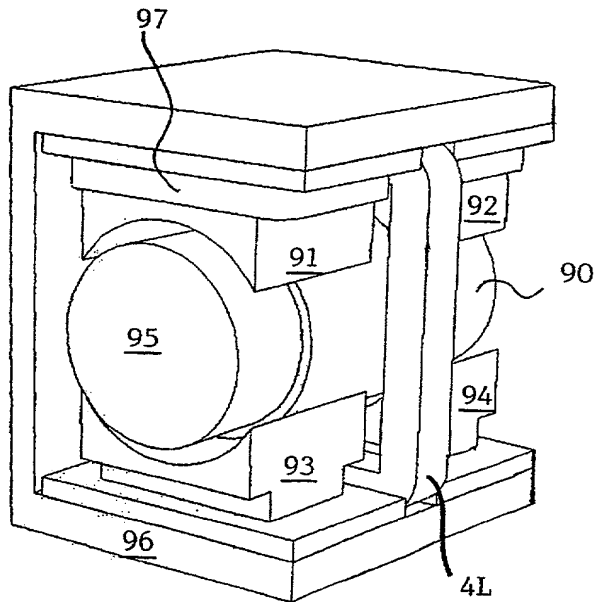


Fig. 22

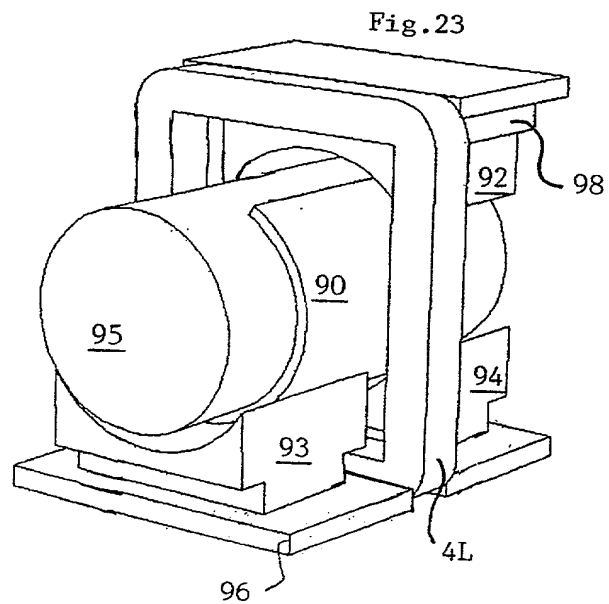


Fig. 23

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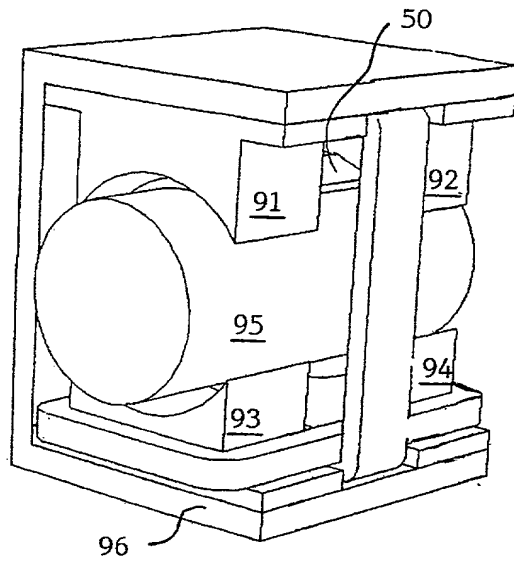


Fig. 24

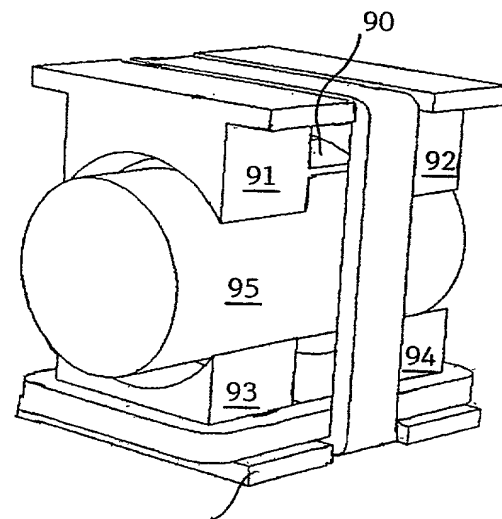


Fig. 25

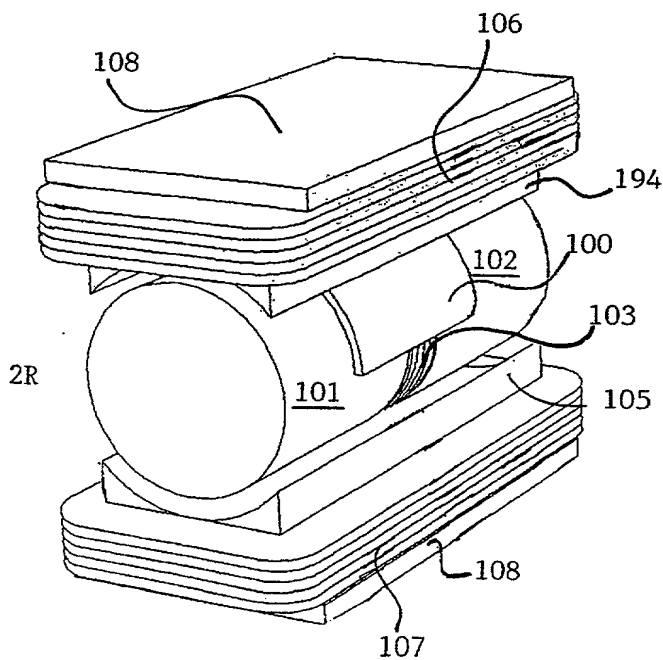


Fig. 26

FIG. 24

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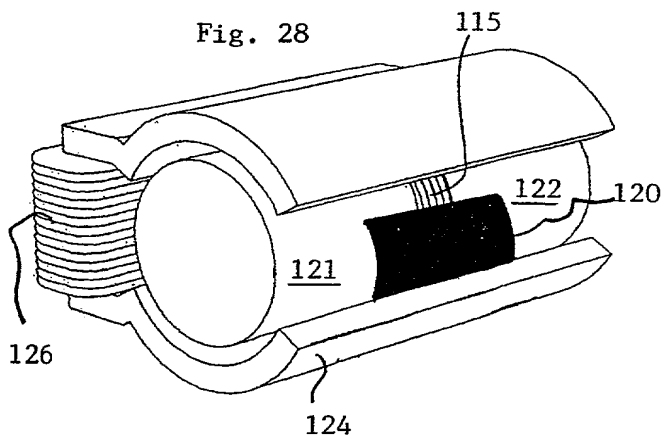
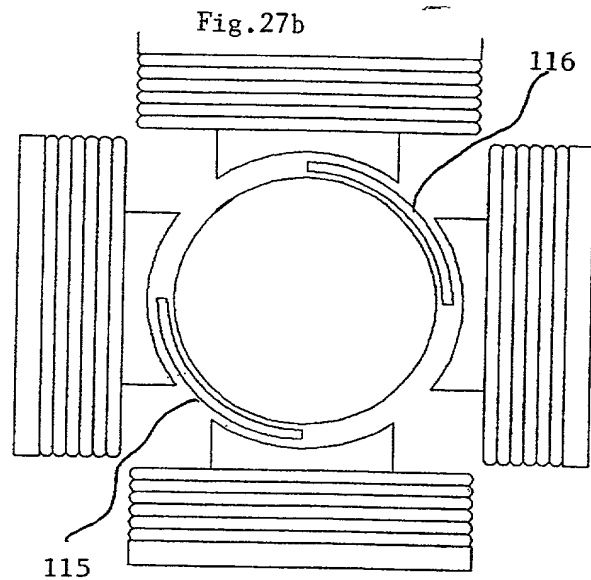
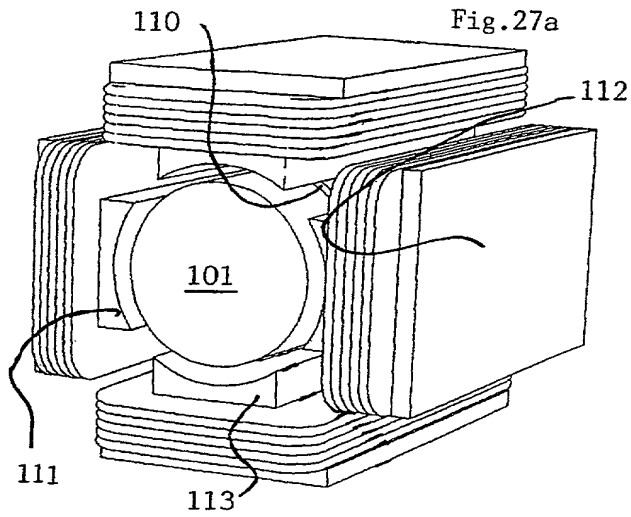


Fig. 29

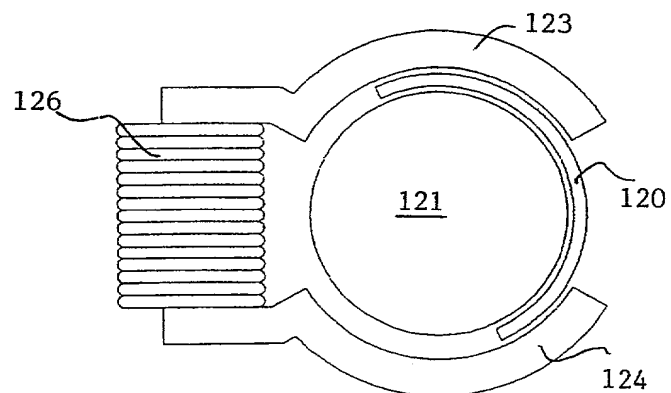


Fig.30

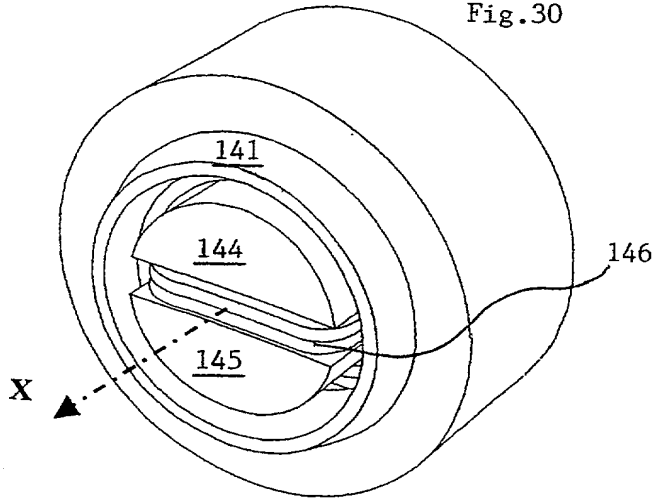


Fig.31

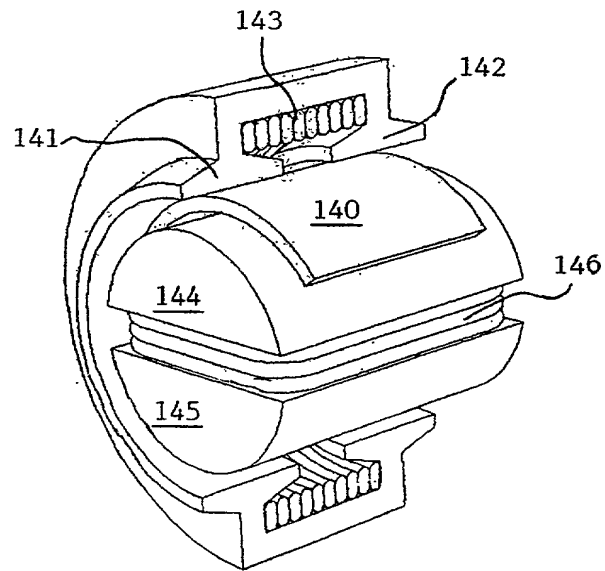
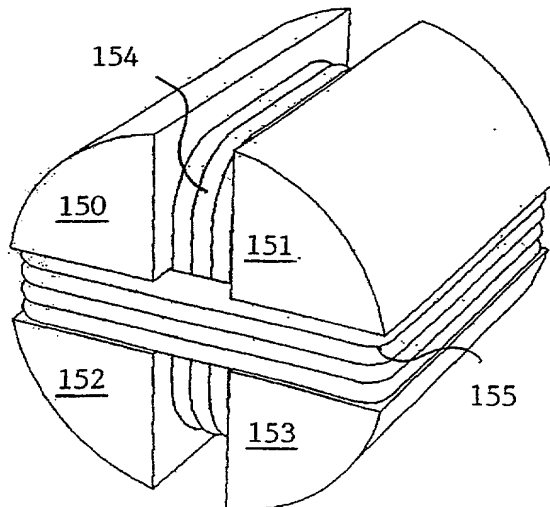


Fig.32



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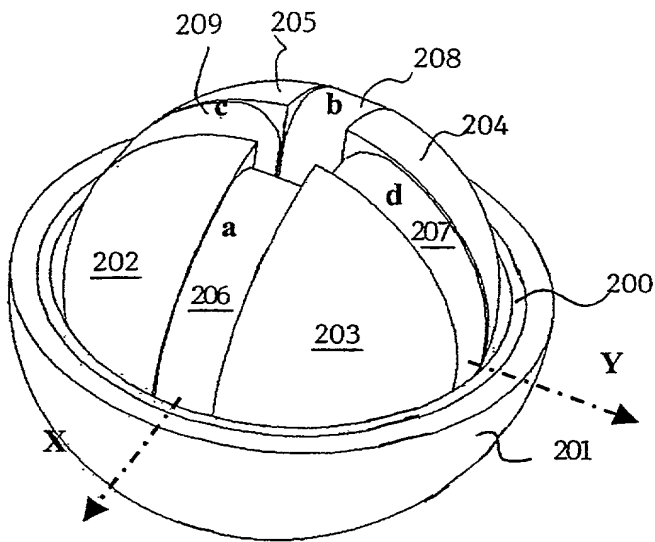


Fig. 33

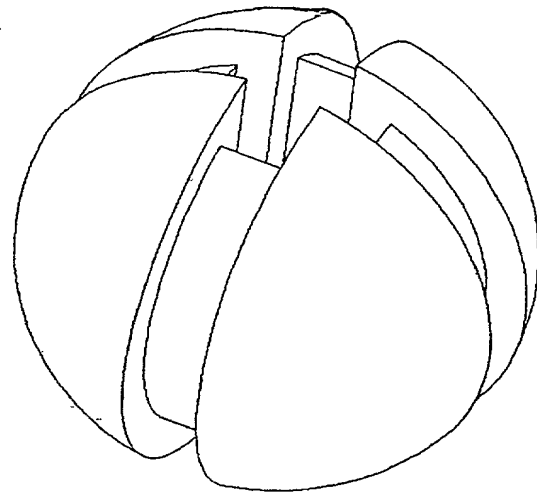


Fig. 34

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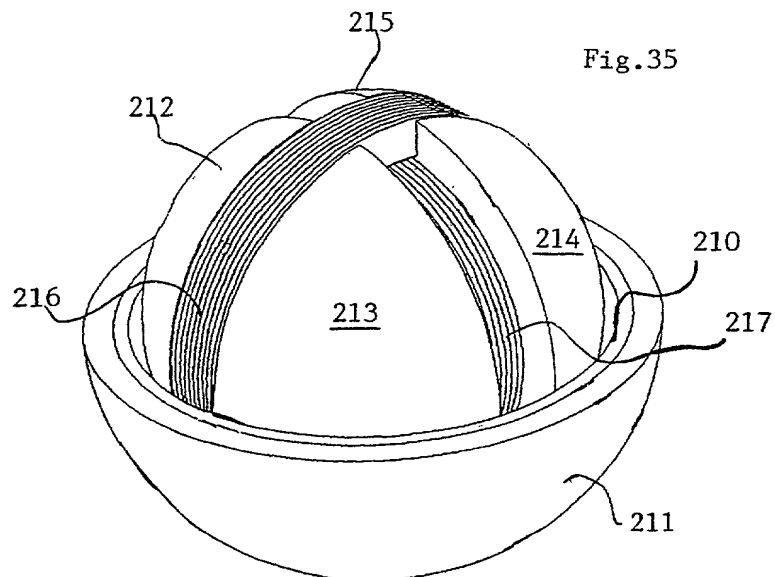
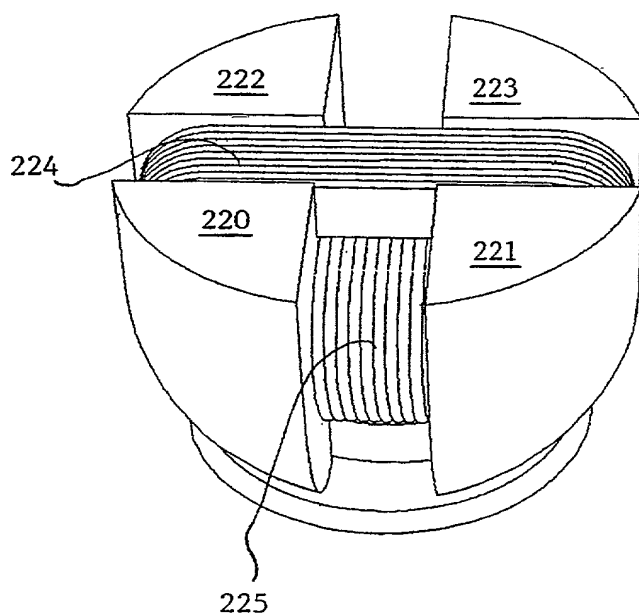


Fig.36



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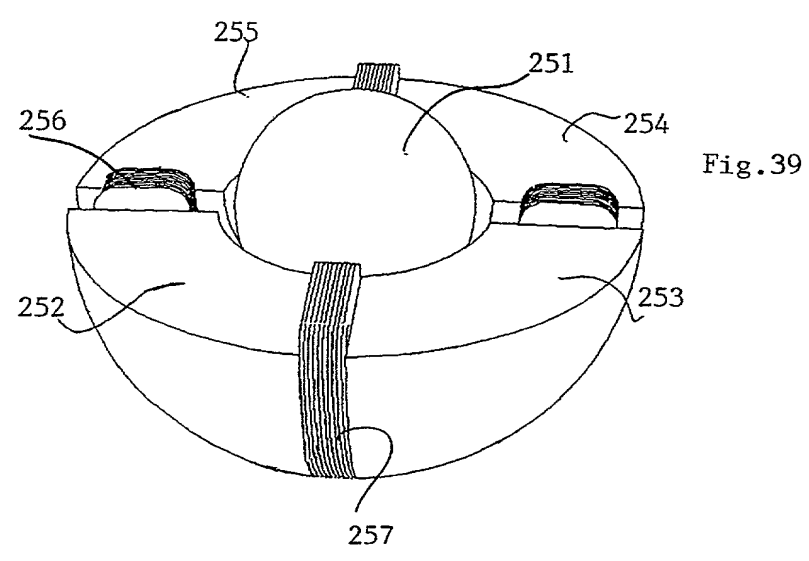


Fig. 40

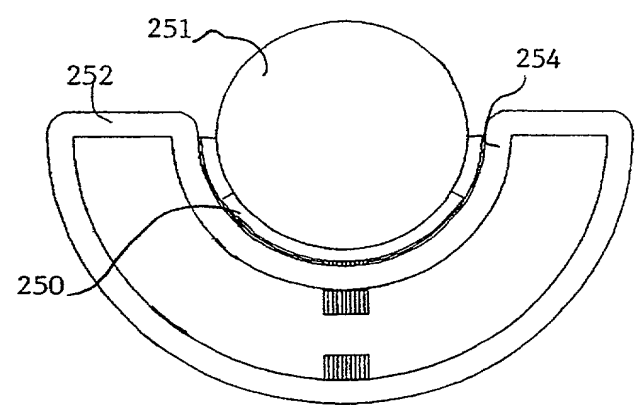


Fig. 41

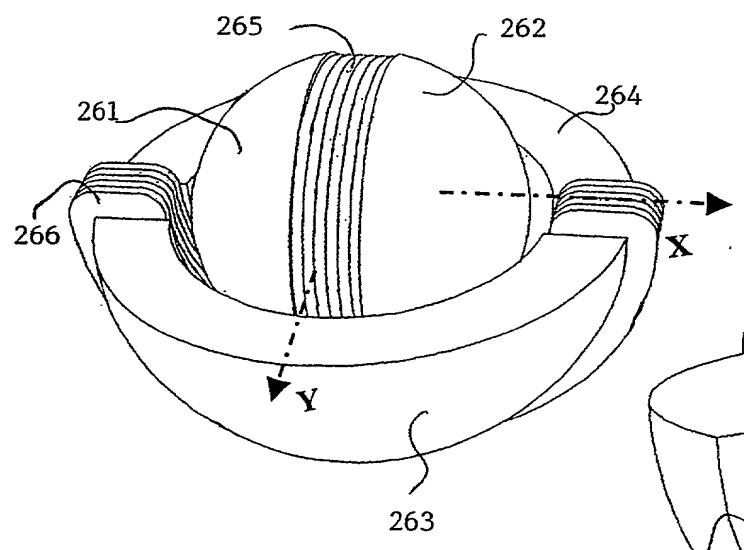
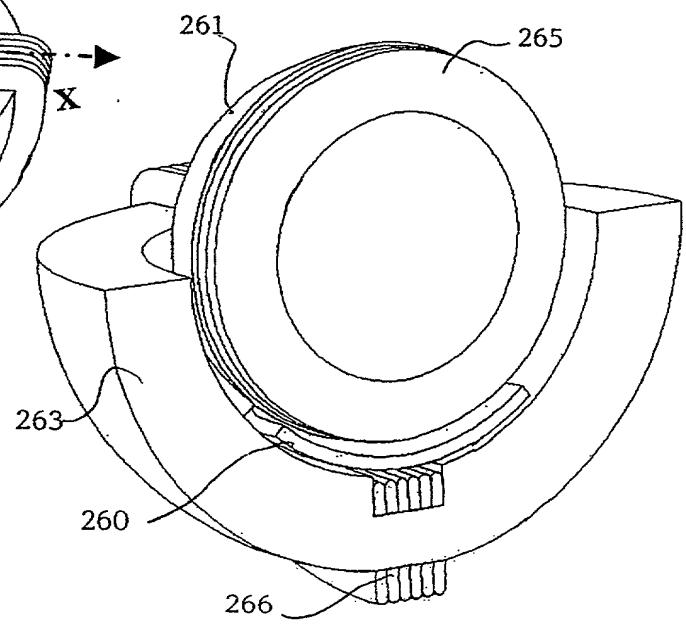


Fig. 42





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Fig.37

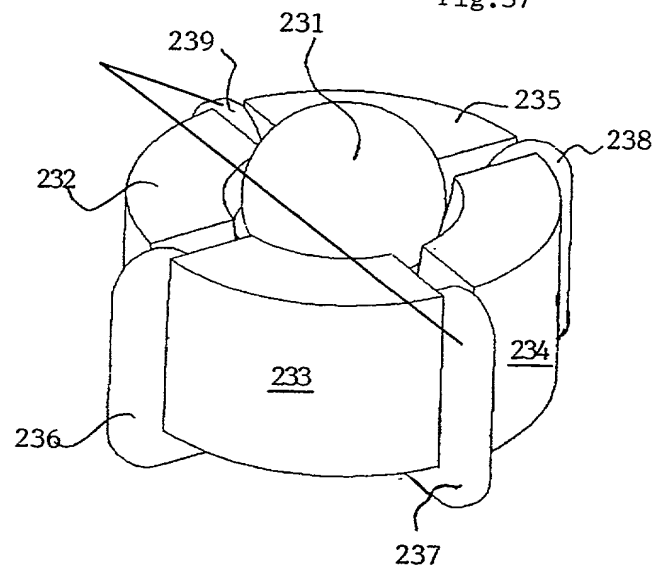
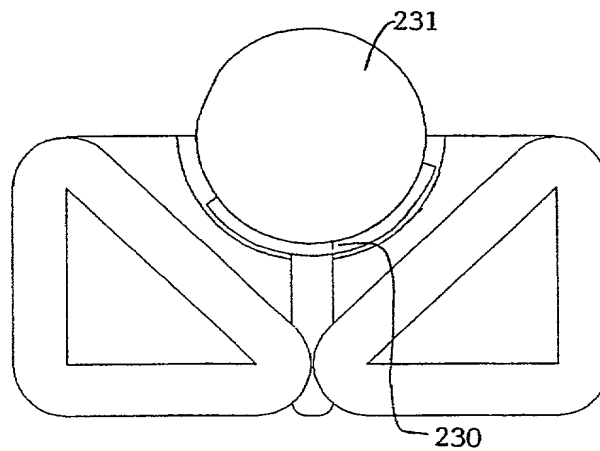


Fig.38



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Fig.44

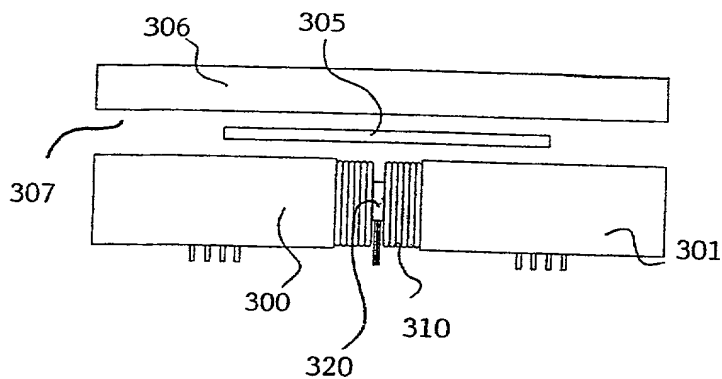
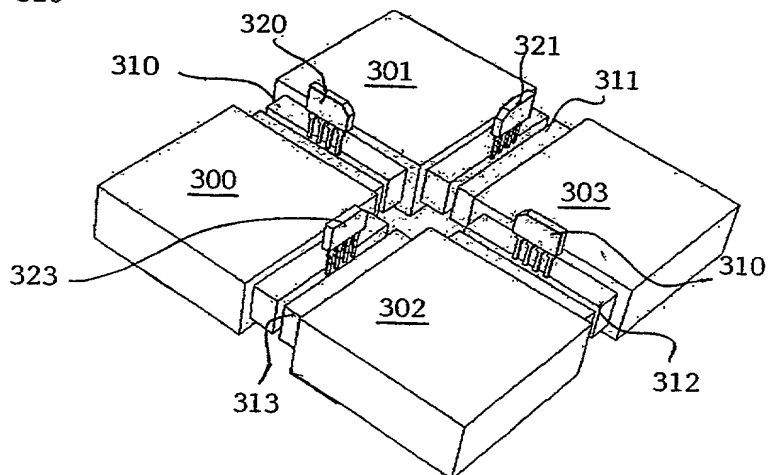


Fig.43



# Declaration and Power of Attorney for Patent Application

## Déclaration et Pouvoirs pour Demande de Brevet

### French Language Declaration

En tant l'inventeur nommé ci-après, je déclare par le présent acte que:

Mon domicile, mon adresse postale et ma nationalité sont ceux figurant ci-dessous à côté de mon nom.

Je crois être le premier inventeur original et unique (si un seul nom est mentionné ci-dessous), ou l'un des premiers co-inventeurs originaux (si plusieurs noms sont mentionnés ci-dessous) de l'objet revendiqué, pour lequel une demande de brevet a été déposée concernant l'invention intitulée

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

#### BIDIRECTIONAL ACTUATORS

et dont la description est fournie ci-joint à moins

☐ ci-joint

☐ a été déposée le \_\_\_\_\_

sous le numéro de demande des Etats-Unis ou le numéro de demande international PCT

\_\_\_\_\_ et modifiée le

\_\_\_\_\_ (le cas échéant).

the specification of which:

☐ is attached hereto.

☒ was filed on May 15, 2001

as United States Application Number or PCT International Application Number

09/831,364 and was amended on

\_\_\_\_\_ (if applicable).

Je déclare par le présent acte avoir passé en revue et compris le contenu de la description ci-dessus, revendications comprises, telles que modifiées par toute modification dont il aura été fait référence ci-dessus.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

Je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

## French Language Declaration

Je revendique par le présent acte avoir la priorité étrangère, en vertu du Titre 35, § 119(a)-(d) ou § 365(b) du Code des Etats-Unis, sur toute demande étrangère de brevet ou certificat d'inventeur ou, en vertu du Titre 35, § 365(a) du même Code, sur toute demande internationale PCT désignant au moins un pays autre que les Etats-Unis et figurant ci-dessous et, en cochant la case, j'ai aussi indiqué ci-dessous toute demande étrangère de brevet, tout certificat d'inventeur ou toute demande internationale PCT ayant une date de dépôt précédant celle de la demande à propos de laquelle une priorité est revendiquée.

I hereby claim foreign priority under Title 35, United States Code, § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below, and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)  
Demande(s) de brevet antérieure(s) dans un autre pays.

Priority claimed  
Droit de priorité  
revendiqué

98/14668      FRANCE  
(Number)      (Country)  
(Numéro)      (Pays)

20 November 1998  
(Day/Month/Year Filed)  
(Jour/Mois/Anné de dépôt)

☒ ☐  
Yes      No  
Oui      Non

\_\_\_\_\_  
(Number)      (Country)  
(Numéro)      (Pays)

\_\_\_\_\_  
(Day/Month/Year Filed)  
(Jour/Mois/Anné de dépôt)

☐ ☐  
Yes      No  
Oui      Non

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 119(e) du Code des Etats-Unis, de toute demande de brevet provisoire effectuée aux Etats-Unis et figurant ci-dessous.

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

\_\_\_\_\_  
(Application No.)  
(N° de demande)

\_\_\_\_\_  
(Filing Date)  
(Date de dépôt)

\_\_\_\_\_  
(Application No.)  
(N° de demande)

\_\_\_\_\_  
(Filing Date)  
(Date de dépôt)

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 120 du Code des Etats-Unis, de toute demande de brevet effectuée aux Etats-Unis, ou en vertu du Titre 35, § 365(c) du même Code, de toute demande internationale PCT désignant les Etats-Unis et figurant ci-dessous et, dans la mesure où l'objet de chacune des revendications de cette demande de brevet n'est pas divulgué dans la demande antérieure américaine ou internationale PCT, en vertu des dispositions du premier paragraphe du Titre 35, § 112 du Code des Etats-Unis, je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations, dont j'ai pu disposer entre la date de dépôt de la demande antérieure et la date de dépôt de la demande nationale ou internationale PCT de la présente demande:

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

PCT/FR99/02771

\_\_\_\_\_  
(Application No.)  
(N° de demande)

10 November 1999

\_\_\_\_\_  
(Filing Date)  
(Date de dépôt)

\_\_\_\_\_  
(Status) (patented, pending, abandoned)  
(Statut) (breveté, en cours d'examen, abandonné)

\_\_\_\_\_  
(Application No.)  
(N° de demande)

\_\_\_\_\_  
(Filing Date)  
(Date de dépôt)

\_\_\_\_\_  
(Status) (patented, pending, abandoned)  
(Statut) (breveté, en cours d'examen, abandonné)

Je déclare par le présent acte que toute déclaration ci-incluse est, à ma connaissance, véridique et que toute déclaration formulée à partir de renseignements ou de suppositions est tenue pour véridique; et de plus, que toutes ces déclarations ont été formulées en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d'une incarcération, ou des deux, en vertu de la Section 1001 du Titre 18 du Code des Etats-Unis, et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

## French Language Declaration

**POUVOIRS:** En tant que l'inventeur cité, je désigne par la présente l'(les) avocat(s) et/ou agent(s) suivant(s) pour qu'ils poursuive(nt) la procédure de cette demande de brevet et traite(nt) toute affaire s'y rapportant avec l'Office des brevets et des marques: (mentionner le nom et le numéro d'enregistrement).

**POWER OF ATTORNEY:** As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: (list name and registration number)



**022850**

Addresser toute correspondance à:

Send Correspondence to:



**022850**

Addresser tout appel téléphonique à:  
(nom et numéro de téléphone)

Direct Telephone calls to: (name and telephone number)

(703) 413-3000

Nom complet de l'unique ou premier inventeur	100	Full name of sole or first inventor	
Signature de l'inventeur	Date	Inventor's signature	Date
Domicile		Residence	8/8/01
Nationalité		Citizenship	8/8/01
Adresse Postale		Post Office Address	
		same as above	
Nom complet du second co-inventeur, le cas échéant		Full name of second joint inventor, if any	
Signature de l'inventeur	Date	Second inventor's signature	Date
Domicile		Residence	
Nationalité		Citizenship	
Adresse Postale		Post Office Address	
		same as above	

(Fournir les mêmes renseignements et la signature de tout co-inventeur supplémentaire.)

(Supply similar information and signature for third and subsequent joint inventors.)